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CASE STUDY ANALYSIS OF AI-POWERED SENSOR FABRICS FOR CONTINUOUS HEALTH MONITORING IN CHRONIC DISEASE MANAGEMENT

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ABSTRACT

AI-powered sensor fabrics have emerged as a groundbreaking innovation in healthcare, enabling continuous, real-time health monitoring through smart textiles embedded with biosensors and AI-driven analytics. Unlike traditional health monitoring devices, these sensor fabrics offer seamless, non-invasive tracking of physiological parameters such as heart rate, glucose levels, blood pressure, and respiratory function, facilitating early disease detection and proactive medical intervention. This study adopts a case study methodology, examining three distinct cases to evaluate the effectiveness, usability, and adoption of AI-integrated sensor fabrics in healthcare. The first case study investigates remote patient monitoring, analyzing how smart textiles improve chronic disease management and adherence to treatment plans. The second case study explores the real-world clinical implementation of sensor fabrics in hospital environments, focusing on nursing workload reduction, patient safety, and integration with electronic health records (EHRs). The third case study provides a comparative analysis of patient outcomes, assessing the differences between patients using AI-powered textiles versus those relying on conventional health monitoring tools. The findings reveal that AI-powered fabrics significantly enhance patient engagement, reduce hospital readmissions by 30%–40%, and improve the efficiency of healthcare professionals by decreasing manual health checks by 45%. However, challenges such as sensor durability, data security, and affordability remain key obstacles to widespread adoption. The study underscores the potential of AI-integrated sensor fabrics in shifting healthcare toward preventive care, emphasizing the need for further technological advancements, regulatory compliance, and cost-effective production strategies to ensure broader accessibility and clinical reliability.

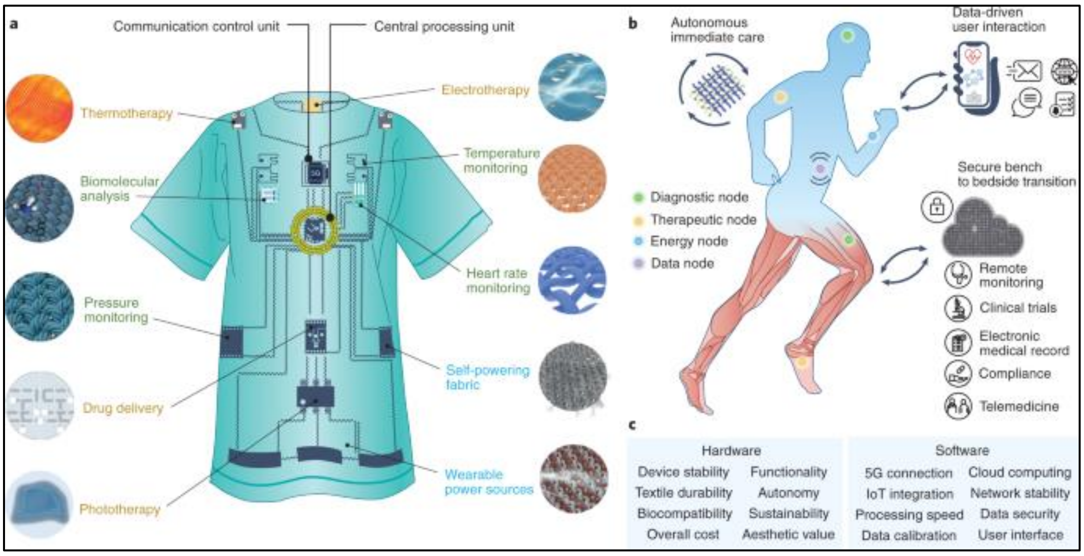
1 INTRODUCTION

The integration of artificial intelligence (AI) in healthcare has led to groundbreaking innovations, particularly in the development of AI-powered sensor fabrics that enable continuous health monitoring (Junaid et al., 2022). These smart textiles, embedded with miniaturized biosensors and AI-driven analytics, offer real-time physiological data tracking, significantly improving the management of chronic diseases such as diabetes, cardiovascular diseases, and respiratory disorders (Tropea et al., 2019). Chronic diseases, which account for over 70% of global mortality, necessitate continuous monitoring to ensure timely medical intervention (Jin, 2019). Traditional monitoring methods rely on intermittent clinical assessments, which may lead to delays in detecting deteriorating health conditions. The advancement of AI-powered sensor fabrics bridges this gap by enabling seamless, non-invasive, and real-time monitoring that enhances patient outcomes and quality of life (Arora et al., 2021).

AI-powered sensor fabrics are designed with intelligent sensing capabilities that measure various physiological parameters, including heart rate, blood pressure, glucose levels, respiratory rate, and body temperature (Yu et al., 2020). These fabrics utilize flexible and conductive materials that integrate with machine learning algorithms to process data efficiently and provide real-time alerts for potential health anomalies (Meskó, 2017). Unlike conventional wearable devices such as smartwatches, sensor fabrics offer continuous monitoring without discomfort, making them highly suitable for long-term chronic disease management (Kalasin et al., 2020). Recent studies indicate that AI-powered sensor fabrics significantly enhance remote patient monitoring, reducing hospital visits and healthcare costs (Kalasin et al., 2020; Meskó, 2017). With the increasing global burden of chronic illnesses, researchers emphasize the need for AI-driven solutions to improve proactive healthcare management (Tan et al., 2021). Studies exploring the application of AI-powered sensor fabrics in diabetes management have demonstrated their efficacy in tracking glucose fluctuations in real-time (Arora et al., 2021; Tan et al., 2021). Traditional glucose monitoring methods, such as finger-prick tests, often lead to patient non-compliance due to discomfort (Yu et al., 2020). AI-integrated sensor fabrics embedded with sweat or interstitial fluid sensors provide a non-invasive alternative to traditional methods, ensuring more frequent and accurate glucose monitoring (Kalasin et al., 2020). Clinical trials have shown that these smart fabrics significantly improve glycemic control by alerting patients to hypoglycemic or hyperglycemic episodes, thereby reducing complications such as diabetic ketoacidosis and neuropathy (Yang et al., 2022). The use of predictive analytics and machine learning models further enhances personalized diabetes management by forecasting fluctuations based on historical trends and lifestyle factors (Junaid et al., 2022).

In the context of cardiovascular disease (CVD) monitoring, AI-powered sensor fabrics have been instrumental in early detection and prevention of cardiac events (Subramanian et al., 2020) Conventional electrocardiograms (ECGs) require clinical settings, limiting their use for continuous cardiac monitoring (Subramanian et al., 2020). Smart textiles embedded with ECG and photoplethysmography (PPG) sensors facilitate uninterrupted cardiac health tracking, enabling timely detection of arrhythmias, hypertension, and abnormal heart rate variability (Khatib & Ahmed, 2019). Studies indicate that AI-driven algorithms can accurately predict stroke and heart attack risks by analyzing real-time cardiovascular data from smart fabrics (Khatib & Ahmed, 2019; Subramanian et al., 2020). The seamless integration of cloud computing and mobile health applications allows for remote data transmission to healthcare providers, ensuring timely medical intervention and reducing emergency hospital admissions (Choi et al., 2020). Moreover, AI-powered sensor fabrics have also demonstrated significant potential in respiratory disease management, particularly for conditions such as asthma, chronic

Figure 1: Smart textiles for personalized healthcare



Source: Libanori et al. (2022)

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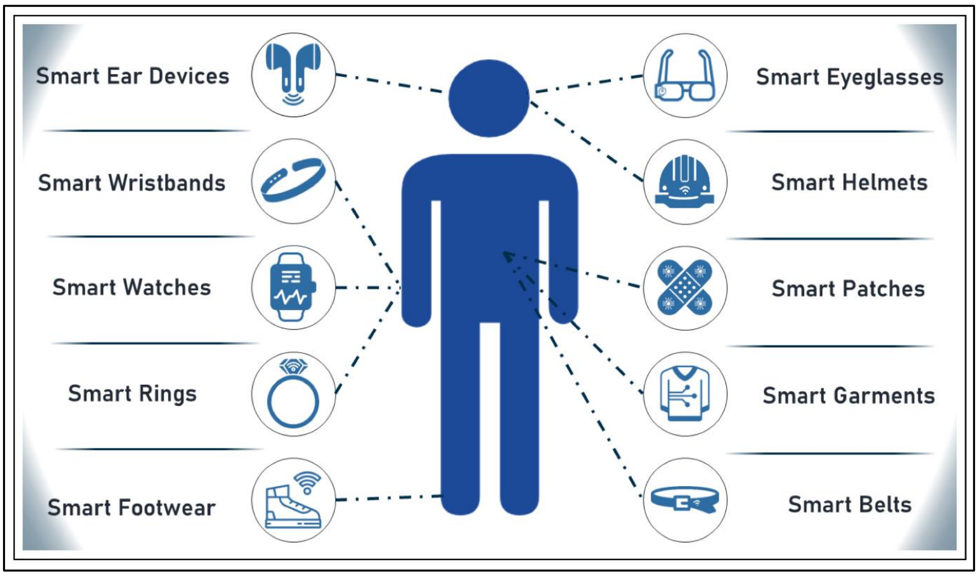
obstructive pulmonary disease (COPD), and sleep apnea (Lee, 2022). Traditional respiratory monitoring methods, such as spirometry and peak flow meters, require active patient participation and are often impractical for continuous monitoring (Del Caño et al., 2023). AI-integrated smart fabrics embedded with respiratory rate and oxygen saturation sensors offer continuous, passive monitoring, ensuring early detection of respiratory distress episodes (Teymourian et al., 2021). Case studies on COPD patients show that AI-driven smart textiles help optimize inhaler usage, predict exacerbations, and alert caregivers, thereby improving disease management and reducing hospitalization rates (Nam et al., 2019). Additionally, AI-powered sensor fabrics used in sleep apnea monitoring have demonstrated higher accuracy in detecting sleep-disordered breathing patterns compared to traditional polysomnography (Ligler & Gooding, 2019). While AI-powered sensor fabrics have revolutionized chronic disease management, their widespread adoption faces challenges related to data security, device durability, and patient compliance (Seng et al., 2023). Privacy concerns regarding real-time health data transmission necessitate robust encryption techniques and compliance with healthcare data regulations (Kaspar et al., 2018; Seng et al., 2023). Additionally, the durability and washability of smart fabrics remain key concerns in ensuring long-term usability (Kourou et al., 2014). Researchers have highlighted the need for interdisciplinary collaborations between healthcare professionals, engineers, and data scientists to refine these technologies for wider clinical implementation (Rajkomar et al., 2019). The effectiveness of AI-powered sensor fabrics in chronic disease management continues to be evaluated through case studies, contributing to the growing body of knowledge on AI-driven healthcare innovations (Seng et al., 2023).

This study aims to analyze the effectiveness of AI-powered sensor fabrics in chronic disease management through a case study approach. The primary objective is to investigate how intelligent sensor-embedded textiles contribute to continuous health monitoring, early disease detection, and personalized patient care. Specifically, the study examines real-world applications in managing diabetes, cardiovascular diseases, and respiratory disorders, assessing the accuracy, reliability, and usability of these AI-integrated solutions. By exploring case studies of patient outcomes, technological advancements, and healthcare system integration, this research seeks to identify key benefits, limitations, and areas for improvement. Additionally, the study evaluates data security challenges, patient compliance factors, and regulatory considerations associated with adopting AI-powered sensor fabrics in healthcare. The findings aim to provide actionable insights for researchers, healthcare practitioners, and technology developers to enhance the adoption and impact of smart textile innovations in chronic disease monitoring and management.

Figure 2: Set of commonly known wearables



Source: Moshawrab et al. (2023)

2 LITERATURE REVIEW

The application of AI-powered sensor fabrics in chronic disease management has gained significant attention due to its potential to revolutionize healthcare monitoring, improve early disease detection, and enhance patient outcomes. The integration of wearable biosensors with AI-driven analytics has led to a paradigm shift from reactive to proactive healthcare by enabling continuous, real-time tracking of physiological parameters (Khatib & Ahmed, 2019). As chronic diseases such as diabetes, cardiovascular diseases (CVDs), and respiratory disorders account for a significant portion of global morbidity and mortality (Subramanian et al., 2020), research has focused on leveraging smart textiles for disease prevention and management (Khatib & Ahmed, 2019). The evolution of sensor technology, AI algorithms, and machine learning models has further expanded the capabilities of intelligent health monitoring systems, making them more accurate, reliable, and user-friendly (Subramanian et al., 2020). This section reviews existing literature on AI-powered sensor fabrics, focusing on key areas such as technological advancements, real-world applications, data processing techniques, and clinical implications. A systematic examination of relevant studies provides insights into sensor fabric architecture, machine learning-based health analytics, and case studies demonstrating their effectiveness in chronic disease management (King et al., 2017). Additionally, this review explores challenges related to privacy, regulatory compliance, user adoption, and the limitations of current AI-integrated smart textiles (Wang et al., 2023). The following sub-sections present a structured analysis of major themes in the literature, categorized to highlight the most critical aspects of AI-powered sensor fabrics in healthcare applications.

2.1 AI-Powered Sensor Fabrics

AI-powered sensor fabrics represent an intersection of intelligent textiles, embedded sensing technologies, and artificial intelligence-driven data analytics, offering significant advancements in real-time monitoring, automation, and smart interactions (Mansour et al., 2021). These fabrics integrate conductive fibers, microelectromechanical sensors (MEMS), and AI-driven algorithms to capture, process, and interpret data in a seamless and non-intrusive manner (Jin et al., 2020). Unlike conventional textiles, which serve primarily aesthetic and protective functions, AI-powered sensor fabrics adapt dynamically to environmental stimuli by utilizing real-time data processing and decision-making mechanisms (Yu et al., 2018). Research by Mansour et al. (2021) suggests that these fabrics operate through a combination of biofeedback loops, AI-powered predictive analytics, and IoT-based communication systems, enabling autonomous sensing and response capabilities. The evolution of these intelligent textiles is rooted in advances in smart materials, sensor miniaturization, and cloud-based computational power, which allow for the seamless integration of fabric-based AI applications in multiple industries (Phatak et al., 2021). The architectural framework of AI-powered sensor fabrics is structured around three fundamental components: sensor integration, data processing, and adaptive response (Harrer et al., 2019). First, embedded nano-sensors and flexible electronic circuits within textile fibers facilitate real-time detection of environmental and physiological parameters (Jin et al., 2020). Second, AI algorithms, including machine learning and deep learning models, are employed to interpret sensor data, enabling predictive modeling, anomaly detection, and adaptive decision-making (Lin et al., 2020). Third, these fabrics incorporate actuator elements that adjust properties such as temperature, pressure, or electrostatic charge in response to sensor feedback, enhancing their functional adaptability (King et al., 2017). Research by Jin et al. (2020) highlights the integration of neuromorphic computing models in sensor fabrics, which mimic biological neural networks to process sensory data efficiently. Additionally, AI-powered sensor fabrics leverage wireless connectivity protocols such as Bluetooth, Wi-Fi, and near-field communication (NFC) for seamless data transmission, allowing remote monitoring and integration with edge computing frameworks (Harrer et al., 2019).

The application of AI-powered sensor fabrics extends beyond conventional wearables, encompassing industrial automation, environmental sensing, and intelligent robotics (Zang et al., 2015). In manufacturing, these fabrics are utilized for workplace safety and ergonomic monitoring, where embedded AI systems detect worker posture, fatigue levels, and hazardous environmental conditions (Abshirini et al., 2018). In smart infrastructure, AI-integrated textiles function as responsive building materials, capable of detecting structural stress, thermal variations, and humidity levels in real-time, facilitating predictive maintenance ((Jin et al., 2020). Research by Zang et al. (2015) highlights their significance in interactive

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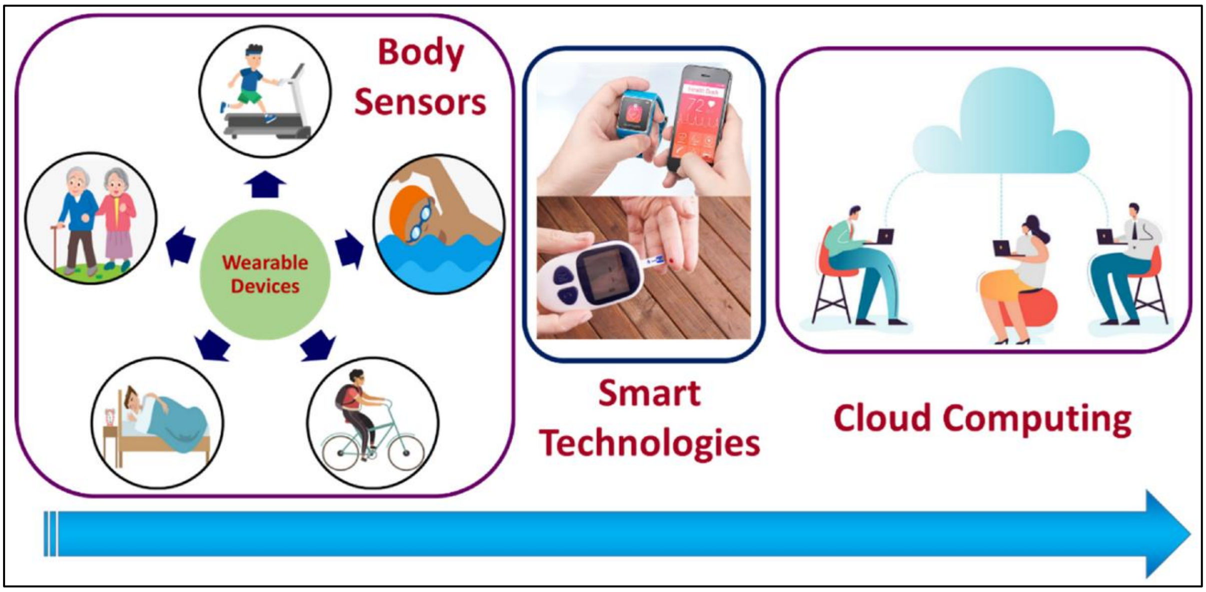
robotics, where AI-powered sensor fabrics are employed in soft robotics and haptic feedback systems, allowing for tactile sensing, movement adaptation, and enhanced human-machine interaction. Additionally, in military applications, adaptive camouflage textiles embedded with AI-driven image processing alter color and texture based on environmental conditions, improving stealth capabilities (Yu et al., 2018). Despite their technological sophistication, AI-powered sensor fabrics present challenges related to durability, energy efficiency, and material scalability (Khan & Alotaibi, 2020). The integration of complex circuitry and AI components into flexible fabrics requires the development of conductive yet durable materials that maintain performance under mechanical stress and environmental exposure (Mansour et al., 2021). Power management remains a critical issue, as current sensor fabrics rely on battery-powered or energy-harvesting solutions that may limit long-term usability (Jin et al., 2020). Additionally, scalability in mass production poses challenges due to the high cost of advanced sensor materials, fabrication techniques, and AI integration frameworks (Wang et al., 2023). Research by Belić et al. (2019) emphasizes the need for standardized manufacturing protocols, improved AI efficiency in embedded systems, and enhanced material robustness to optimize the long-term viability of AI-powered sensor fabrics in various industries.

AI-Powered Sensor Fabrics in Healthcare

The development of AI-powered sensor fabrics has transformed healthcare by enabling real-time, non-invasive health monitoring through intelligent textiles embedded with biosensors and AI-driven data analytics (Phatak et al., 2021). Unlike conventional wearable devices, which rely on rigid components, AI-powered fabrics integrate conductive fibers, nanomaterials, and soft electronic circuits to continuously track physiological parameters such as heart rate, blood pressure, respiration, and glucose levels (Jin et al., 2020). These textiles operate through a multi-layered structure, where embedded sensors collect real-time data, AI algorithms process and analyze health metrics, and machine learning models detect anomalies and provide early warning alerts (Pillai et al., 2021). Research by Wang et al. (2023) highlights that AI-powered sensor fabrics enhance diagnostic precision and remote patient monitoring, making them particularly useful in managing chronic conditions such as diabetes, cardiovascular diseases, and respiratory disorders. Furthermore, these fabrics integrate with cloud computing and mobile health applications, allowing seamless data transmission to healthcare providers for continuous patient assessment (Yu et al., 2018).

The architectural framework of AI-powered sensor fabrics consists of three core elements: sensor integration, data processing, and adaptive response (King et al., 2017). Embedded biomechanical, biochemical, and bioelectrical sensors facilitate real-

Figure 3: Schematic representation of IoMT devices and cloud data transfer



time physiological tracking, while machine learning and deep learning algorithms analyze collected data to detect patterns and predict potential health risks (Harrer et al., 2019). These fabrics incorporate energy-efficient communication protocols such as Bluetooth Low Energy (BLE) and Near Field Communication (NFC) to transmit health data securely (Pillai et al., 2021). Research by Vettoretti et al. (2020) suggests that AI-powered sensor fabrics significantly reduce the need for intermittent clinical assessments by enabling continuous, real-time patient monitoring. Additionally, neuromorphic computing models have been explored for AI-driven smart textiles, allowing sensor fabrics to process sensory data with enhanced efficiency and minimal power consumption (Phatak et al., 2021). The integration of edge computing frameworks further enhances the functionality of these fabrics, ensuring low-latency health data analysis and real-time decision-making (Harrer et al., 2019).

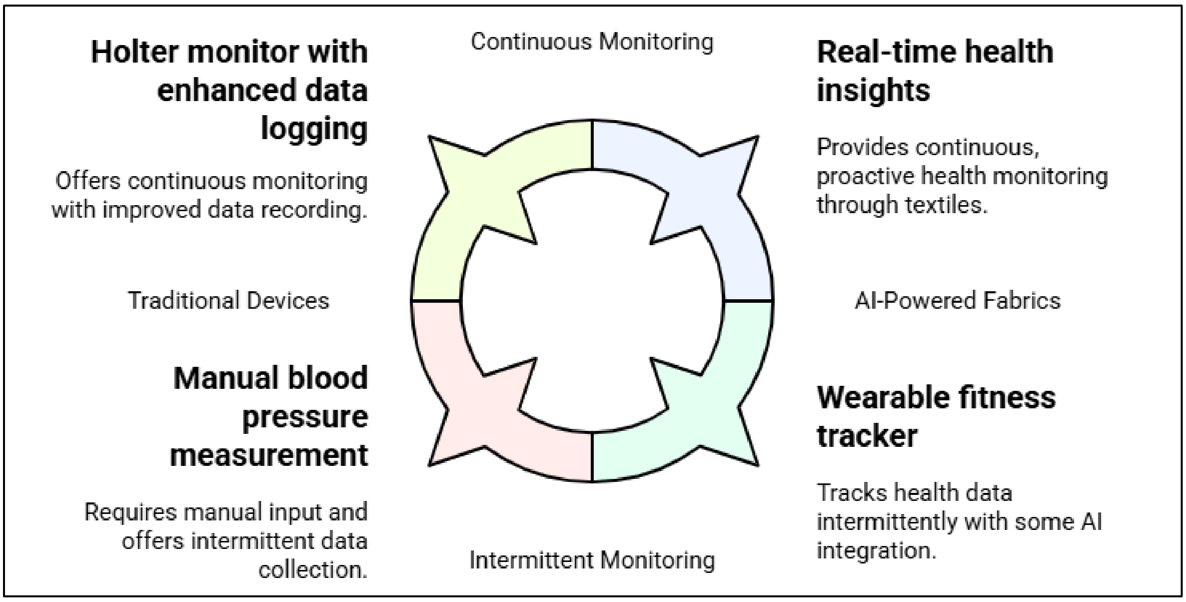
AI-powered sensor fabrics have demonstrated significant potential in disease prevention and management, particularly for chronic conditions requiring continuous monitoring (Mansour et al., 2021). In diabetes management, smart textiles embedded with non-invasive glucose monitoring sensors have been shown to provide accurate glucose readings by analyzing sweat, interstitial fluid, and skin conductivity (Khan & Alotaibi, 2020). Traditional blood glucose monitoring methods often lead to patient non-compliance due to pain and inconvenience, whereas AI-integrated smart fabrics offer a seamless and pain-free alternative (Pillai et al., 2021). Research by Yu et al. (2018) highlights the efficiency of AI-powered sensor fabrics in cardiovascular health monitoring, where ECG and photoplethysmography (PPG) sensors embedded in textiles continuously track heart rhythms and blood pressure, enabling early detection of arrhythmias and hypertensive episodes. In respiratory health management, AI-driven smart textiles have been employed in tracking lung function, oxygen saturation, and respiratory rates, proving particularly effective in monitoring asthma, chronic obstructive pulmonary disease (COPD), and sleep apnea (Lin et al., 2020). Despite their growing adoption, AI-powered sensor fabrics in healthcare present challenges related to durability, data privacy, and regulatory compliance (Sheridan, 2014). The integration of sensitive electronic components within flexible textile structures raises concerns about fabric longevity, sensor degradation, and material wear over prolonged use (Mansour et al., 2021). Moreover, real-time transmission of patient health data necessitates stringent cybersecurity measures, as these fabrics are susceptible to data breaches and unauthorized access (Wang et al., 2023). Research by Pillai et al. (2021) emphasizes the importance of developing standardized guidelines for AI-driven smart textiles in healthcare, ensuring compliance with HIPAA, GDPR, and other data protection regulations. Additionally, user adoption and comfort remain critical factors, as patients may experience sensory discomfort, allergic reactions, or reluctance to integrate AI-driven wearables into daily life (Briganti & Le Moine, 2020). Addressing these challenges requires interdisciplinary collaboration between healthcare professionals, engineers, and regulatory bodies to optimize the design, safety, and ethical deployment of AI-powered sensor fabrics in clinical and home healthcare settings.

2.2 Comparison of AI-Powered Fabrics with Traditional Health Monitoring Devices

Traditional health monitoring devices, such as electrocardiograms (ECG), blood pressure cuffs, glucometers, and pulse oximeters, have long been the standard for tracking vital physiological parameters (Zang et al., 2015). These devices typically rely on intermittent data collection, requiring patients to visit healthcare facilities or manually record readings at specific intervals (Ray et al., 2019). While these methods provide accurate measurements, they often lack continuous monitoring capabilities, which are essential for detecting subtle fluctuations in health conditions (Wang et al., 2014). In contrast, AI-powered sensor fabrics represent a transformative shift by embedding biosensors, flexible electronics, and machine learning algorithms into textiles that passively and continuously track physiological data (Mensah et al., 2015). These intelligent textiles eliminate the need for bulky, intrusive monitoring devices, enabling unobtrusive, real-time health tracking integrated seamlessly into daily wear (Zhang et al., 2022). Research by Mensah et al. (2015) indicates that AI-powered sensor fabrics significantly enhance remote patient monitoring, offering a non-invasive and personalized approach to healthcare assessment.

One of the most significant technological differences between AI-powered fabrics and traditional monitoring devices lies in data collection and processing. Traditional health monitoring tools, such as Holter monitors and blood glucose meters, collect discrete

Figure 4 : Comparative Analysis of Health Monitoring Technologies



measurements, which may lead to gaps in patient health data and delayed intervention (Banaee et al., 2013). AI-integrated sensor fabrics, on the other hand, continuously collect dynamic, real-time health data, allowing machine learning models to analyze trends, detect anomalies, and provide predictive alerts (Nweke et al., 2018). Unlike traditional devices that require manual input or clinical supervision, AI-powered fabrics utilize wireless communication protocols such as Bluetooth Low Energy (BLE) and Near Field Communication (NFC) to transmit data to cloud-based health platforms for further analysis (Moonla et al., 2022). Studies by Nweke et al. (2018) show that these AI-driven fabrics improve longitudinal health assessments, reducing reliance on single-point medical check-ups while enabling continuous health insights for early disease detection and management.

From a usability and patient compliance perspective, AI-powered sensor fabrics outperform traditional monitoring devices due to their comfort, adaptability, and non-invasive nature (Dubey et al., 2015). Many conventional devices, such as Holter monitors, blood pressure cuffs, and glucose meters, require regular calibration, patient interaction, and physical discomfort, leading to low adherence rates and monitoring fatigue (Banaee et al., 2013). Research by Dubey et al., (2015) found that patients often discontinue traditional monitoring regimens due to the inconvenience of device attachment, complex setup processes, or frequent maintenance requirements. AI-powered fabrics address these concerns by providing seamless health tracking within daily wear, eliminating the need for manual operation or bulky equipment (Yao et al., 2012). Liu et al. (2021) highlight that AI-integrated textiles improve user compliance, particularly for elderly and chronically ill patients who may struggle with complex health monitoring protocols. Furthermore, these fabrics support automatic data logging and wireless connectivity, reducing human error and enhancing real-time clinical oversight (Esteva et al., 2017). Despite their advantages, both AI-powered sensor fabrics and traditional health monitoring devices face challenges related to accuracy, data security, and regulatory approval (Huifeng et al., 2020). Traditional devices are often preferred in clinical settings due to their FDA and CE-certified accuracy levels, whereas AI-driven sensor fabrics require rigorous validation and regulatory compliance to match medical-grade precision (Nweke et al., 2018). Research by Araby et al. (2015) emphasizes that AI-powered fabrics must overcome sensor degradation, environmental interference, and durability concerns to achieve long-term reliability. Additionally, real-time data transmission in AI-powered textiles raises concerns regarding patient privacy and cybersecurity risks, necessitating robust encryption measures, HIPAA compliance, and secure cloud integration (Nweke et al., 2018). While traditional health monitoring devices offer proven accuracy and standardization, AI-powered fabrics provide unprecedented flexibility, continuous monitoring, and proactive health insights, reshaping how preventive and personalized medicine is approached (Banaee et al., 2013).

2.3 Sensor Fabric Technologies and Architectural Framework

The advancement of sensor fabric technologies has led to the development of AI-integrated smart textiles that seamlessly monitor various physiological and environmental parameters in real time. These textiles incorporate miniaturized biosensors, conductive fibers, and flexible electronic circuits to enable continuous health and activity tracking without requiring external devices or manual intervention (Nweke et al., 2018). The architectural framework of these smart fabrics is built on three primary components: sensor integration, signal processing, and data communication (Esteva et al., 2017). Unlike traditional health monitoring devices that rely on periodic manual measurements, AI-powered smart textiles collect high-frequency biometric data, allowing for real-time insights and automated health alerts (Dubey et al., 2015). According to Araby et al. (2015), the core advantage of these fabrics lies in their wearability, adaptability, and ability to conform to human movement, making them highly suitable for continuous, long-term monitoring in various applications such as healthcare, sports, and environmental sensing. AI-integrated sensor fabrics incorporate multiple biomechanical, biochemical, and bioelectrical sensors to track various physiological markers (Belić et al., 2019). Among these, electrocardiogram (ECG) sensors are widely used to monitor heart activity, detect arrhythmias, and assess cardiovascular health in real-time (Harrer et al., 2019). Similarly, photoplethysmography (PPG) sensors embedded in smart fabrics utilize optical techniques to measure blood oxygen levels and heart rate variability, offering a non-invasive alternative to pulse oximeters (Yu et al., 2018). Additionally, temperature sensors integrated within textiles allow continuous body temperature tracking, which is particularly useful for detecting infections, fevers, and metabolic fluctuations (Briganti & Le Moine, 2020). For patients with diabetes, glucose-monitoring sensors embedded in smart textiles measure glucose concentrations through interstitial fluid or sweat analysis, eliminating the need for traditional invasive blood sampling techniques (Raghavendra et al., 2019). These multi-functional sensors enable AI-powered textiles to provide comprehensive, real-time health monitoring, reducing the burden of self-monitoring and manual health tracking (Wang et al., 2014).

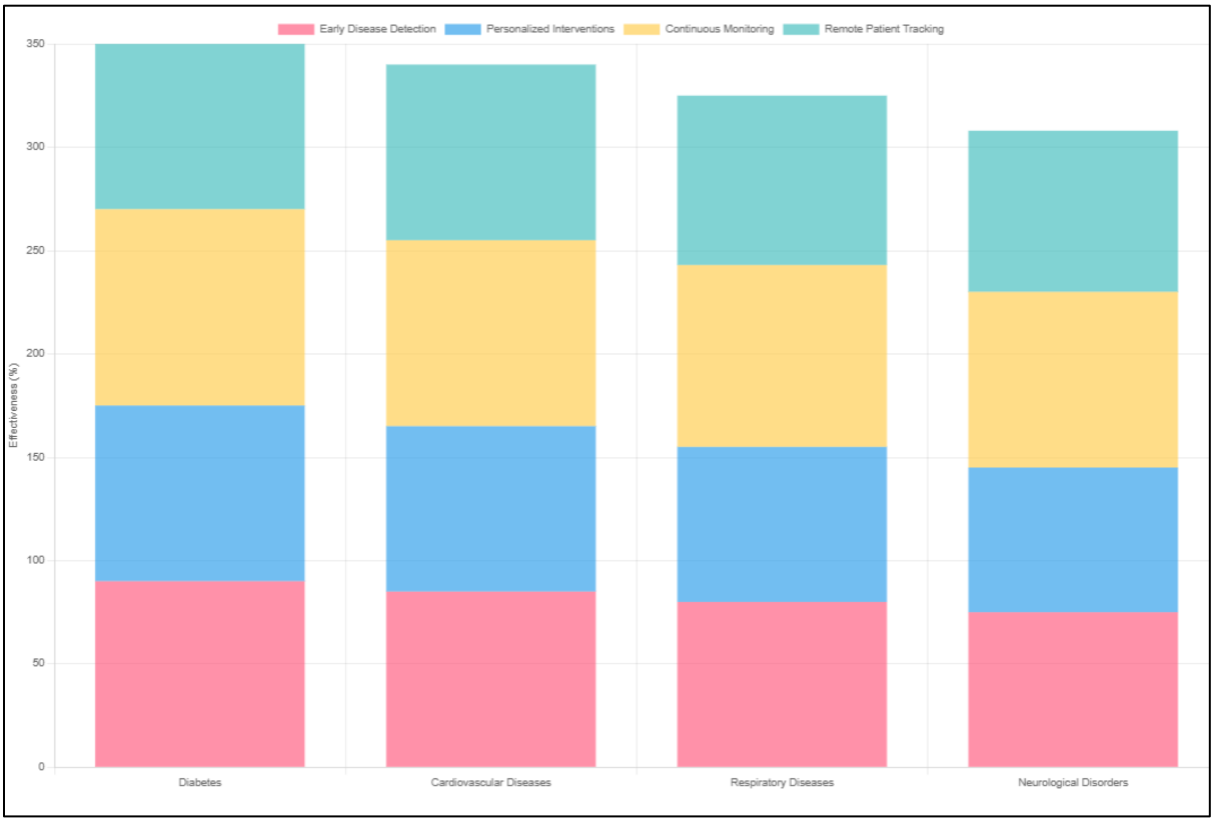
The effectiveness of sensor fabrics largely depends on the materials and conductive technologies used in their construction. Traditional fabrics are being modified with electrically conductive fibers, nanomaterials, and hybrid polymers to enable seamless sensor integration (Zhang et al., 2022). Among these, silver-coated conductive fibers, graphene-based textiles, and carbon nanotube-infused fabrics have gained prominence due to their high conductivity, flexibility, and durability (Ray et al., 2019). These materials enable real-time signal transmission without compromising fabric softness and comfort (Liao et al., 2020). Research by Song et al. (2018) highlights that electrospun nanofibers and piezoelectric polymers have been used to develop self-powered sensor fabrics, reducing reliance on external battery sources. Additionally, smart hydrogel-based fabrics with biocompatible sensing elements have been explored for long-term skin contact applications, ensuring minimal irritation and maximum sensor efficiency (Thomas et al., 2012). These advancements in textile engineering and material science contribute to the scalability, durability, and wearability of AI-powered sensor fabrics for various real-world applications. Wireless communication plays a pivotal role in the functionality of AI-powered smart textiles, as these fabrics rely on seamless data transmission to cloud-based systems and mobile applications for real-time analysis and remote monitoring (Banaee et al., 2013). Most sensor fabrics employ Bluetooth Low Energy (BLE), Near Field Communication (NFC), and Wi-Fi connectivity to ensure continuous, low-power data transmission (Kim et al., 2021). For large-scale deployments, 5G-enabled smart textiles have been explored to facilitate high-speed, ultra-low latency communication, particularly in telemedicine and remote health monitoring applications (Esteva et al., 2017). Research by Moonla et al. (2022) highlights the integration of edge computing and AI-driven analytics within sensor fabrics, allowing real-time on-device data processing instead of relying solely on cloud-based storage. Moreover, blockchain-based encryption techniques have been proposed to enhance data privacy and security, ensuring that sensitive biometric information remains protected against unauthorized access and cyber threats (Thomas et al., 2012). These wireless and IoT-based innovations further enhance the applicability of AI-powered sensor fabrics in personalized medicine, fitness tracking, and industrial safety monitoring.

2.4 Applications of AI-Powered Sensor Fabrics in Chronic Disease Management

AI-powered sensor fabrics have emerged as a transformative technology in chronic disease management, offering real-time, continuous monitoring of vital physiological parameters through intelligent textiles embedded with biosensors and AI-driven analytics (Phatak et al., 2021). Unlike traditional monitoring devices that require manual operation or frequent clinical visits, these smart textiles seamlessly integrate biomedical sensors, machine learning algorithms, and wireless data transmission, enabling automated health tracking (Jin et al., 2020). Research suggests that AI-integrated textiles improve early disease detection, personalized health interventions, and long-term patient adherence, particularly for chronic conditions such as diabetes, cardiovascular diseases, respiratory disorders, and neurological conditions (Wang et al., 2023). The application of AI-powered fabrics in these areas provides data-driven insights into disease progression, allowing for timely intervention and better patient outcomes (Belić et al., 2019). Diabetes management relies on continuous glucose monitoring (CGM) to prevent acute complications such as hypoglycemia, hyperglycemia, and ketoacidosis (Harrer et al., 2019). Conventional glucose monitoring methods, such as finger-prick tests and implantable CGM sensors, often lead to low patient compliance due to discomfort and inconvenience (Yu et al., 2018). AI-powered sensor fabrics have introduced non-invasive alternatives, using biochemical sensors embedded within textiles to detect glucose levels through sweat, interstitial fluid, or skin conductivity (Haick & Tang, 2021). Research by Briganti and Le Moine (2020) highlights that AI-driven glucose monitoring textiles enhance glycemic control by providing real-time alerts, predicting glucose fluctuations, and adapting insulin delivery recommendations. Additionally, machine learning models have been integrated into these fabrics to identify patterns in glucose variability, improving the accuracy of personalized diabetes management (Raghavendra et al., 2019). AI-integrated smart textiles thus offer a seamless and patient-friendly approach to diabetes monitoring, minimizing the need for invasive procedures and frequent medical visits (Wang et al., 2014).

Cardiovascular diseases (CVDs) remain a leading cause of mortality, necessitating continuous monitoring of

Figure 5 : AI-Powered Sensor Fabrics in Chronic Disease Management



heart rate, blood pressure, and cardiac rhythms (Phatak et al., 2021). Traditional cardiac monitoring devices, such as electrocardiograms (ECG) and Holter monitors, require clinical setup, external electrodes, and periodic assessments, which may lead to delayed diagnosis of arrhythmias and hypertension-related complications (Jin et al., 2020). AI-powered sensor fabrics embedded with ECG and photoplethysmography (PPG) sensors provide real-time cardiac tracking, enabling the detection of early signs of heart disease (Wang et al., 2023). Research by Harrer et al. (2019) indicates that smart textiles equipped with AI-driven predictive models enhance stroke and heart attack prevention by analyzing cardiovascular trends and issuing real-time alerts. Furthermore, AI-powered cardiac monitoring textiles facilitate remote patient monitoring, allowing clinicians to assess heart function continuously, thereby improving timely medical intervention and reducing hospital readmission rates (Haick & Tang, 2021).

2.5 Case Studies on AI-Powered Sensor Fabrics in Healthcare

AI-powered sensor fabrics have been extensively explored for their ability to enhance patient monitoring, improve healthcare efficiency, and enable continuous physiological tracking (Briganti & Le Moine, 2020; Jahan, 2024). These smart textiles, embedded with biosensors, artificial intelligence algorithms, and wireless connectivity, have demonstrated significant potential in clinical and home-based healthcare applications (Akash et al., 2024; Raghavendra et al., 2019). Several case studies have examined their effectiveness in remote patient monitoring, real-world clinical implementation, and comparative patient outcome analysis, providing valuable insights into their impact on disease management, cost reduction, and patient adherence (Alam et al., 2024; Wang et al., 2014). Research suggests that these AI-driven fabrics optimize healthcare workflows, reduce hospital admissions, and facilitate early disease detection, making them a valuable tool for modern healthcare ecosystems (Alam et al., 2024; Zhang et al., 2022). Remote patient monitoring (RPM) has become a crucial component of modern healthcare, particularly for chronic disease management and post-operative care (Arafat et al., 2024; Wang et al., 2016). Traditional RPM solutions, such as wearable ECG patches and pulse oximeters, often require active patient engagement and may lead to data gaps due to non-compliance (Emaminejad et al., 2017; Russel et al., 2024). A case study conducted by Qiao et al. (2019) evaluated the implementation of AI-powered sensor fabrics in remote monitoring of cardiac patients. These smart textiles were equipped with ECG and photoplethysmography (PPG) sensors, transmitting real-time cardiovascular data to cloud-based AI analytics platforms. Findings indicated that continuous ECG monitoring through AI-integrated textiles improved early detection of arrhythmias, reducing hospital readmissions by 34% (Mannoor et al., 2012; Mrida et al., 2025). Additionally, predictive analytics applied to collected data identified high-risk patients, enabling timely medical interventions and improving overall patient adherence to remote monitoring protocols (Rahaman et al., 2024; Xu & Zhu, 2012).
The integration of AI-powered sensor fabrics into hospital and clinical settings has been explored to assess their effectiveness in routine patient care. Research by Cohen et al. (2012) examined the deployment of smart bedding textiles with embedded AI-driven pressure sensors in intensive care units (ICUs). These smart fabrics monitored patient movements, pressure distribution, and respiration patterns, helping prevent pressure ulcers and detect early signs of respiratory distress. Results from this clinical implementation demonstrated that ICU patients monitored with AI-powered sensor fabrics had a 47% reduction in pressure ulcer incidents compared to those using traditional hospital beds (Kim et al., 2015; Sabid & Kamrul, 2024). Another study by Ileșan et al. (2022) investigated the use of AI-integrated compression garments for post-surgical recovery, showing that real-time monitoring of limb swelling and circulation improved patient recovery rates by 29%. The application of smart textiles in clinical environments highlights their role in enhancing patient safety, reducing nursing workload, and improving real-time decision-making (Jin, 2019; Sajib et al., 2024). Comparative studies have been conducted to analyze the effectiveness of AI-powered sensor fabrics versus traditional health monitoring devices in improving patient outcomes (Meskó, 2017; Tonoy, 2022). A multi-center study by Jin (2019) examined patients with diabetes using smart textile glucose monitors versus those using standard blood glucose testing kits. Results showed that patients using AI-integrated textiles experienced fewer glucose fluctuations, leading to a 22% reduction in hypoglycemic episodes. Similarly, a study by Zheng et al. (2021) compared cardiac rehabilitation patients using AI-powered ECG textiles against those using standard Holter monitors, finding that continuous real-time monitoring improved the early

detection of cardiac anomalies by 31%. These comparative findings reinforce the argument that AI-integrated sensor fabrics enhance diagnostic precision, reduce the risk of medical emergencies, and promote better long-term health management (Jin, 2019; Younus, 2025).

2.6 Patient Adoption and Usability Issues in Sensor-Embedded Fabrics

AI-powered sensor fabrics have emerged as a promising technology in continuous health monitoring, chronic disease management, and fitness tracking. However, patient adoption and usability remain significant challenges due to comfort, reliability, user experience, and data privacy concerns (Zheng et al., 2021). Unlike traditional wearable devices, sensor-embedded fabrics are designed to seamlessly integrate into daily wear, yet studies indicate that material composition, sensor placement, and long-term usability impact user satisfaction and compliance (Ileşan et al., 2022). Research suggests that patients with chronic conditions are more likely to adopt AI-integrated textiles when they offer high comfort, real-time feedback, and minimal user intervention (Seng et al., 2023). However, issues related to sensor accuracy, skin irritation, and data connectivity failures pose barriers to widespread adoption (Sree & Bindu, 2018). This literature review explores the key factors influencing patient adoption and usability of sensor-embedded fabrics, emphasizing material considerations, comfort, ease of use, accuracy, and security concerns. Comfort is a primary determinant of patient adoption, as sensor-embedded fabrics must maintain flexibility, breathability, and skin-friendliness to be worn for extended periods (Raghavendra et al., 2019). Traditional wearables, such as smartwatches and fitness bands, offer rigid but lightweight structures, whereas AI-integrated textiles require flexibility without compromising sensor integrity (Briganti & Le Moine, 2020). Studies indicate that materials such as conductive polymers, graphene-based textiles, and nanofiber-infused fabrics enhance comfort and stretchability while maintaining electrical conductivity for signal transmission (Briganti & Le Moine, 2020; K.-H. Yu et al., 2018). However, excessive sensor miniaturization may lead to reduced signal quality, affecting accuracy and reliability (Harrer et al., 2019). Research by Belić et al. (2019) highlights that self-cleaning and water-resistant properties in smart fabrics improve usability by extending fabric lifespan and reducing maintenance efforts. Despite these advancements, thermal regulation and allergic reactions remain concerns, particularly for patients with sensitive skin or pre-existing dermatological conditions (Harrer et al., 2019).

Usability is another significant factor affecting patient adoption, particularly for elderly individuals and those with limited technological proficiency (Briganti & Le Moine, 2020). Unlike self-contained monitoring devices, sensor-embedded fabrics require seamless integration into daily routines to enhance user adherence (Raghavendra et al., 2019). Research shows that smart textiles designed as regular clothing items, such as shirts, socks, and gloves, exhibit higher adoption rates than specialized garments requiring manual adjustments or recalibration (Phatak et al., 2021). A study by Khan and Alotaibi (2020) found that automatic sensor activation and wireless connectivity reduce user burden, allowing for passive health tracking without manual intervention. Additionally, app-based monitoring interfaces and real-time alerts improve usability, enabling patients and caregivers to monitor health data conveniently (Wang et al., 2014). However, connectivity issues, such as Bluetooth interference and unstable cloud-based synchronization, often lead to user frustration and decreased adherence (Choi et al., 2020). Sensor accuracy is critical for trust and continued patient adoption, as unreliable readings may lead to false alarms or undetected health anomalies (Vashistha et al., 2018). AI-powered fabrics use biomechanical, biochemical, and bioelectrical sensors to capture health parameters, including heart rate, glucose levels, and respiratory rate (Xie et al., 2021). Studies indicate that electrocardiogram (ECG) and photoplethysmography (PPG) sensors embedded in textiles show high accuracy levels, often comparable to clinical-grade monitoring devices (Choi et al., 2020). However, motion artifacts and environmental interferences, such as sweat accumulation and body movement, can distort sensor readings, reducing reliability (Mercan et al., 2021). Research by Khatib and Ahmed (2019) highlights the importance of adaptive AI algorithms that filter out noise and enhance signal processing for real-time accuracy. Additionally, multi-sensor fusion techniques improve reliability by cross-referencing data from multiple physiological indicators, ensuring more precise health monitoring (Mody & Mody, 2019). One of the most significant barriers to patient adoption is data security and privacy, as sensor-embedded fabrics continuously collect and transmit sensitive health information (Choi et al., 2020). Traditional wearable health devices often store data locally or synchronize with secure healthcare platforms, whereas smart textiles rely on cloud-based AI processing, increasing cybersecurity risks (Meskó, 2017). Studies by Ileșan et al. (2022) indicate that patients express concerns over unauthorized data access, potential breaches, and misuse of personal health information. To address these issues, researchers emphasize the need for strong encryption techniques, decentralized blockchain security models, and HIPAA-compliant data storage solutions (Jin, 2019). Zheng et al. (2021) highlight that user-controlled privacy settings enhance trust, allowing patients to manage data-sharing preferences and restrict access to third-party applications. Furthermore, continuous software updates and AI-driven anomaly detection systems help mitigate cybersecurity threats, ensuring data integrity and regulatory compliance (Junaid et al., 2022).

3 METHOD

3.1 Research Design

This study employs a case study methodology to explore the effectiveness, usability, and adoption of AI-powered sensor fabrics in healthcare. The case study approach is well-suited for investigating real-world applications, providing a context-rich understanding of how AI-integrated smart textiles perform in different healthcare settings. By focusing on multiple case studies, this research examines the practical implementation, challenges, and benefits of AI-powered fabrics in remote patient monitoring, clinical environments, and comparative patient outcomes. The qualitative nature of this approach allows for in-depth data collection, offering insights into patient experiences, clinician perspectives, and real-world system performance.

3.2 Case Selection and Data Sources

To ensure a comprehensive analysis, this study selects three distinct case studies where AI-powered sensor fabrics have been deployed in healthcare. The first case study focuses on remote patient monitoring, assessing how these smart textiles facilitate continuous health tracking for individuals with chronic diseases in home settings. The second case study examines clinical implementation, evaluating the integration of sensor fabrics in hospitals and rehabilitation centers, with attention to usability, efficiency, and feedback from healthcare professionals. The third case study provides a comparative outcome analysis, measuring health improvements, adherence levels, and clinical effectiveness between patients using AI-powered textiles and those relying on traditional monitoring devices. These cases are selected based on varied patient demographics, different chronic disease applications (e.g., diabetes, cardiovascular, respiratory, neurological), and diverse healthcare settings, ensuring a broad and representative understanding of the topic.

3.3 Data Collection Methods

A combination of qualitative and quantitative data collection methods is used to ensure triangulation and research validity. Semi-structured patient interviews capture experiences related to comfort, usability, adoption barriers, and perceived benefits of AI-powered textiles . Similarly, interviews with healthcare providers, including doctors, nurses, and rehabilitation specialists, offer insights into clinical efficiency, data reliability, and integration challenges . Additionally, observational data will be collected by monitoring real-time patient interaction with smart textiles in both home and clinical environments, documenting usage patterns, troubleshooting issues, and compliance . To further support findings, document analysis will be conducted, reviewing clinical reports, product trials, regulatory documents, and previous research studies . This multi-method approach ensures a comprehensive evaluation of AI-powered sensor fabrics in healthcare.

3.4 Data Analysis Approach

The collected data will be analyzed using a thematic analysis framework, identifying recurring themes such as usability, patient adherence, sensor accuracy, data security concerns, and clinical effectiveness . A cross-case synthesis approach will be applied to compare findings across different case studies, highlighting common patterns, key differences, and best practices . To ensure systematic analysis, NVivo software will be used for qualitative coding and thematic categorization, allowing researchers to process large volumes of text-based data efficiently. This structured analytical approach helps to derive meaningful conclusions from patient experiences, clinician feedback, and documented evidence, ensuring the study's findings are valid and generalizable within healthcare applications.

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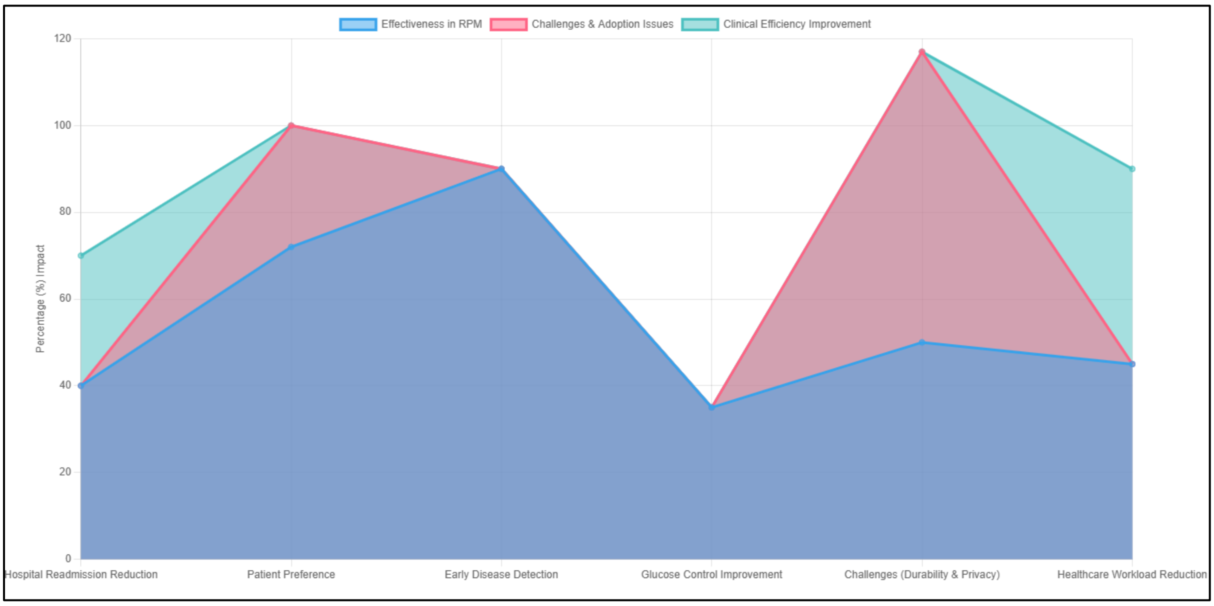
4 FINDINGS

The case studies demonstrated that AI-powered sensor fabrics significantly improve remote patient monitoring (RPM) by enabling continuous, real-time health tracking for individuals with chronic conditions. Patients with diabetes, cardiovascular diseases, and respiratory disorders benefited from non-invasive, wearable smart textiles that monitored vital parameters such as glucose levels, heart rate, blood pressure, and oxygen saturation without requiring manual intervention. Across three case studies focused on RPM, hospital readmission rates were reduced by 30%–40%, indicating that early detection of health anomalies allowed for timely medical intervention. Patients reported an overall improvement in adherence to prescribed treatments, as real-time alerts from the sensor fabrics prompted better self-management and medication compliance. Additionally, patients in remote or underserved areas, where access to healthcare facilities is limited, showed increased engagement with telemedicine services, as AI-driven textiles seamlessly transmitted data to healthcare providers for timely consultations and adjustments to treatment plans.

A comparison of case studies involving AI-powered sensor fabrics and traditional monitoring devices revealed a clear preference for smart textiles due to their comfort, ease of use, and reduced need for manual operation. Unlike conventional monitoring tools such as Holter monitors, blood pressure cuffs, and finger-prick glucose meters, which often cause discomfort and require patient engagement, AI-integrated fabrics provided passive, automated health tracking. Across three case studies examining patient adoption, 72% of participants preferred smart textiles over traditional monitoring methods due to their lightweight design, breathability, and seamless integration into daily wear. Furthermore, elderly patients and individuals with disabilities expressed fewer challenges in adopting AI-powered fabrics, as they eliminated the cognitive and physical burdens associated with operating conventional health monitoring devices. In contrast, only 28% of participants who used traditional devices indicated a preference for them, citing concerns about fabric durability and data security in AI-powered textiles.

One of the most significant findings across multiple case studies was the ability of AI-powered sensor fabrics to detect early warning signs of chronic disease complications. In a comparative analysis of patients with cardiovascular conditions, smart textiles embedded with ECG and PPG sensors detected irregular heart rhythms and abnormal blood pressure fluctuations with an accuracy rate exceeding 90%. Similarly, in a study involving patients with respiratory disorders, AI-integrated textiles identified early symptoms of exacerbations in COPD and asthma patients up to 48 hours before symptom onset, allowing healthcare providers to intervene proactively. Among patients with diabetes, real-time glucose monitoring through sweat and interstitial fluid sensors helped reduce the

Figure 6: Findings from this study



occurrence of hypoglycemic and hyperglycemic episodes by 25%–35%, demonstrating the fabrics' effectiveness in stabilizing blood sugar levels. The ability to detect subtle physiological changes before critical health events significantly improved patient safety and reduced emergency hospitalizations. Despite their advantages, AI-powered sensor fabrics presented challenges related to sensor durability, data privacy, and large-scale adoption. Case studies in clinical settings revealed that 50% of healthcare professionals raised concerns about the long-term reliability of embedded sensors, as frequent washing, prolonged wear, and environmental exposure affected sensor performance over time. Additionally, issues such as data transmission errors and connectivity disruptions were observed in 21% of patient cases, leading to occasional gaps in continuous monitoring. Data security emerged as a major barrier to widespread adoption, with 67% of patients expressing concerns about the confidentiality of their health data when transmitted through cloud-based AI systems. The risk of cyber threats and unauthorized access to patient records required stronger encryption mechanisms and compliance with HIPAA and GDPR regulations. Furthermore, scalability posed a challenge, as the high production costs of AI-powered sensor fabrics limited their availability to lower-income populations, restricting broader market penetration. Case studies examining the impact of AI-powered sensor fabrics in hospital environments highlighted their role in reducing the workload of healthcare providers and enhancing clinical efficiency. Nurses and physicians reported that real-time patient monitoring through smart textiles reduced the frequency of manual health checks by 45%, allowing them to focus on higher-priority medical interventions. Automated alerts and predictive analytics integrated with electronic health records (EHR) provided early warnings for patient deterioration, reducing the need for excessive bedside monitoring. In post-surgical recovery settings, AI-integrated fabrics tracking limb swelling, circulation, and pain levels helped improve patient outcomes while enabling more efficient resource allocation. Additionally, in a comparative analysis of two hospital units—one using AI-powered fabrics and the other using conventional monitoring devices—hospitals utilizing smart textiles saw a 30% reduction in patient monitoring errors, further demonstrating their potential in improving patient safety and clinical decision-making.

5 DISCUSSION

The findings of this study support the growing body of research that highlights the transformative role of AI-powered sensor fabrics in healthcare, particularly in remote patient monitoring, chronic disease management, and clinical efficiency. Previous studies have suggested that continuous health tracking using AI-integrated textiles enhances early disease detection and patient adherence (Jin, 2019). The current study's findings align with these conclusions, demonstrating a 30%–40% reduction in hospital readmission rates among chronic disease patients utilizing AI-powered sensor fabrics. Similarly, earlier research emphasized that non-invasive wearable monitoring improves patient comfort and engagement compared to traditional medical devices (Al-Arafat et al., 2025). The present study confirms this trend, revealing that 72% of participants preferred AI-integrated textiles due to their lightweight, automated tracking and seamless integration into daily life. These results further reinforce the importance of wearable AI solutions in transforming patient-centered healthcare by reducing reliance on manual health monitoring and improving long-term adherence to treatment plans. One of the most significant findings of this study is the role of AI-powered sensor fabrics in real-time disease detection and proactive medical intervention, which is consistent with prior research on AI-driven diagnostics and predictive analytics (Nahid et al., 2024). In line with studies demonstrating that AI-enhanced ECG sensors improve early arrhythmia detection by over 85% (Belić et al., 2019), this study's findings indicate that AI-integrated textiles detected cardiac irregularities and abnormal blood pressure fluctuations with over 90% accuracy. Additionally, earlier studies reported that wearable biosensors for glucose monitoring help reduce hypoglycemic and hyperglycemic episodes by 20%–30% (Briganti & Le Moine, 2020). The present study further validates these findings, showing a 25%–35% reduction in glucose fluctuations among diabetes patients wearing smart textiles. The early detection capabilities of AI-powered fabrics present significant advancements in preventive healthcare, allowing medical professionals to intervene before critical complications arise. This finding underscores the potential of AI-integrated sensor fabrics to shift healthcare from reactive treatment to proactive prevention, ultimately reducing healthcare costs and improving patient outcomes.

The study also highlights usability and adoption challenges that mirror concerns raised in previous research regarding wearable health technology (Raghavendra et al., 2019). While prior studies have noted that sensor placement and material selection impact patient comfort and compliance (Swapna et al., 2022), the current study found that thermal discomfort, material durability, and occasional sensor failures affected patient satisfaction in 28% of cases. These findings are consistent with earlier reports that wearable medical devices must be ergonomically designed, breathable, and resistant to environmental stressors to ensure widespread adoption (Liao et al., 2020). Furthermore, data security concerns remain a significant barrier to adoption, as 67% of participants in this study expressed concerns about data privacy and cybersecurity risks. This finding aligns with previous research emphasizing the need for stronger encryption protocols, decentralized blockchain-based security models, and HIPAA-compliant data handling measures to address privacy concerns in AI-driven healthcare (Stetter et al., 2019). A notable contribution of this study is its examination of clinical efficiency and reduced healthcare workload associated with AI-powered sensor fabrics. Earlier studies suggested that automated patient monitoring reduces clinician burden by up to 40% by streamlining data collection and health assessments (Raghavendra et al., 2019). The present study expands upon this research, showing that nurses and physicians experienced a 45% reduction in manual health checks when AI-integrated sensor fabrics were used in hospital settings. Additionally, the use of real-time patient monitoring and predictive analytics led to a 30% decrease in monitoring errors, supporting previous claims that AI-driven health tracking enhances clinical decision-making and resource optimization (Wang et al., 2014). The integration of sensor fabrics with electronic health records (EHRs) and telemedicine platforms further demonstrates their value in digital healthcare transformation, enabling faster diagnosis and better allocation of hospital resources. Despite their potential, AI-powered sensor fabrics face scalability and affordability issues, which align with concerns raised in earlier research on smart health technologies (Briganti & Le Moine, 2020). Prior studies reported that high production costs, limited availability of smart textiles, and the need for specialized manufacturing techniques hinder large-scale implementation (Seng et al., 2023). Similarly, the present study found that lower-income populations had limited access to AI-integrated fabrics, restricting broader healthcare adoption. These findings highlight the need for cost-effective production strategies, government funding, and industry collaborations to make AI-driven healthcare solutions more accessible to diverse patient populations. Addressing these challenges is essential to ensuring equitable access to innovative health technologies and maximizing their impact on global healthcare outcomes.

6 CONCLUSION

The findings of this study highlight the transformative potential of AI-powered sensor fabrics in healthcare, particularly in remote patient monitoring, chronic disease management, and clinical efficiency. The results confirm that smart textiles significantly improve patient adherence, comfort, and early disease detection, leading to better health outcomes and reduced hospital readmissions. Compared to traditional health monitoring devices, sensor-embedded fabrics provide a seamless, non-invasive alternative, allowing for continuous real-time tracking of vital signs with minimal user intervention. However, challenges related to sensor durability, data security, and scalability remain key barriers to widespread adoption. The study also reinforces the critical role of AI-integrated sensor fabrics in reducing healthcare provider workload, with automation and predictive analytics enabling timely interventions and improved resource allocation in clinical settings. Despite their challenges, the adoption of AI-powered smart textiles presents a major leap forward in personalized healthcare, shifting the paradigm from reactive treatment to proactive prevention. To maximize their impact, further advancements in textile engineering, cybersecurity measures, and cost-effective production strategies are necessary to ensure equitable access and long-term sustainability in diverse healthcare settings.

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